CHAPTER FIVE

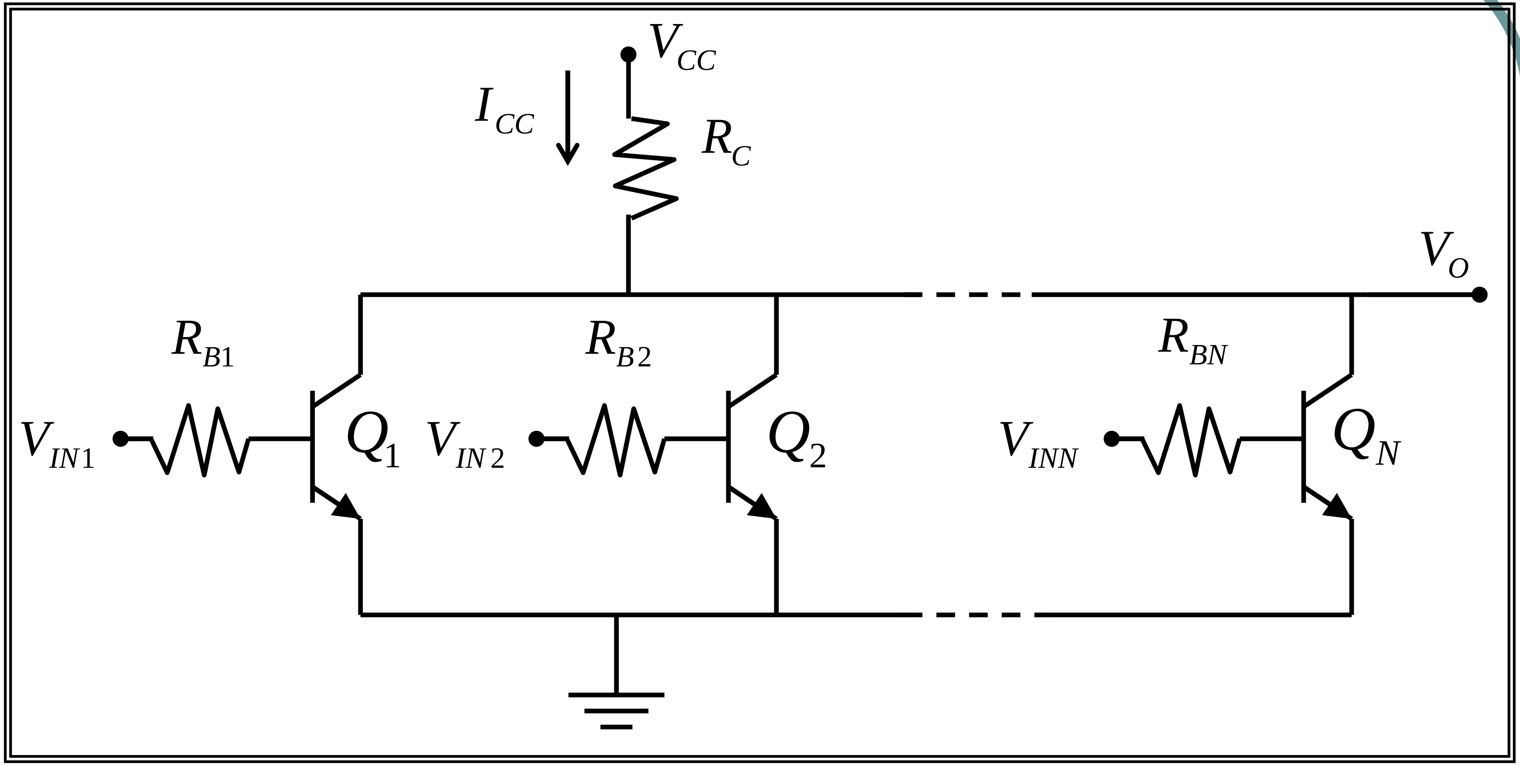
RTL NOR Gate

Digital Electronics.

Introduction

- RTL Inverter: discussed in Ch.4
- RTL NOR gate
- RTL NAND gate
- RTL OR gate
- RTL AND gate

Basic RTL NOR Gate



$$I_{CC} = \sum_{n=1}^{N} I_{Cn}$$

$$Vo = V_{CC} - I_{CC} R_C$$

If all inputs are less than V_{BE}(FA) ⇒ $V_O = V_{CC}$ High

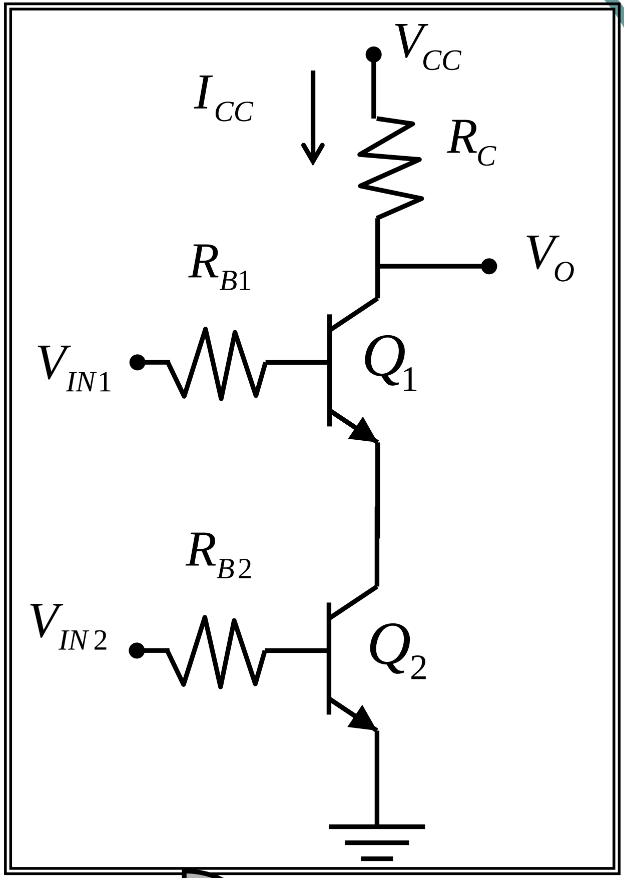
If at <u>least one input</u> is greater than V_{IH} ⇒ $V_O = V_{CE}(sat)$ Low

Basic RTL NAND Gate

Assuming $\beta_F >> 1$, I_B is negligible to I_C

$$I_{CC} = I_{C1} \cong I_{E1} \cong I_{E2}$$

$$Vo = V_{CC} - I_{CC} R_C$$



If at least one input less than V_{BE}(FA), then the corresponding Q is off. i.e. $I_{CC}=0$

$$V_{OH} = V_{CC}$$

$$V_O = V_{CE}(sat)$$

Q_2 starts conducting (ON) if $V_{IN2} > V_{BE2}$(FA)

Q_1 starts conducting (ON) if $V_{IN1} > V_{BE1}(FA) + V_{CE2}(sat)$

V_O starts decreasing below V_{CC}

If both Q_1 and Q_2 are saturated
$V_O = 2V_{CE}(sat)$

Multi-Input RTL NAND Gate

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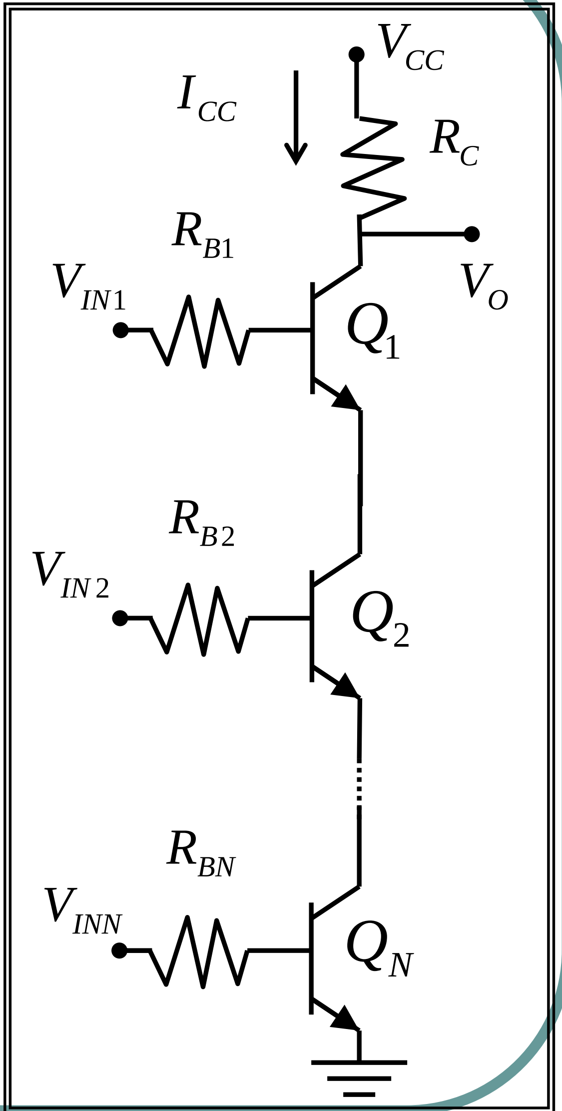
$$V_{OH} = V_{CC} - I_{CC} R_C$$

$$V_{OL} = \sum_{n=1}^{N} V_{CEn}(sat)$$

Note: Number of inputs of an RTL NAND is limited



- Example

Determine the maximum fan-in for basic RTL NAND gate, assuming $V_{CE}(sat)=0.2V$, $V_{BE}(FA)=0.7V$

- Solution

MUST $N_{ML} = V_{IL} - V_{OL} > 0 \qquad N_{MH} = V_{OH} - V_{IH} > 0$

$$V_{IL} > V_{OL} \Rightarrow 0.7 > N \times V_{CE}(sat)$$

$$N < \frac{0.7}{0.2} = 3.5 \Rightarrow N = 3$$

Always valid

$$V_{OH} > V_{IH} \Rightarrow V_{CC} > V_{BE}(FA)$$

RTL Fan-Out

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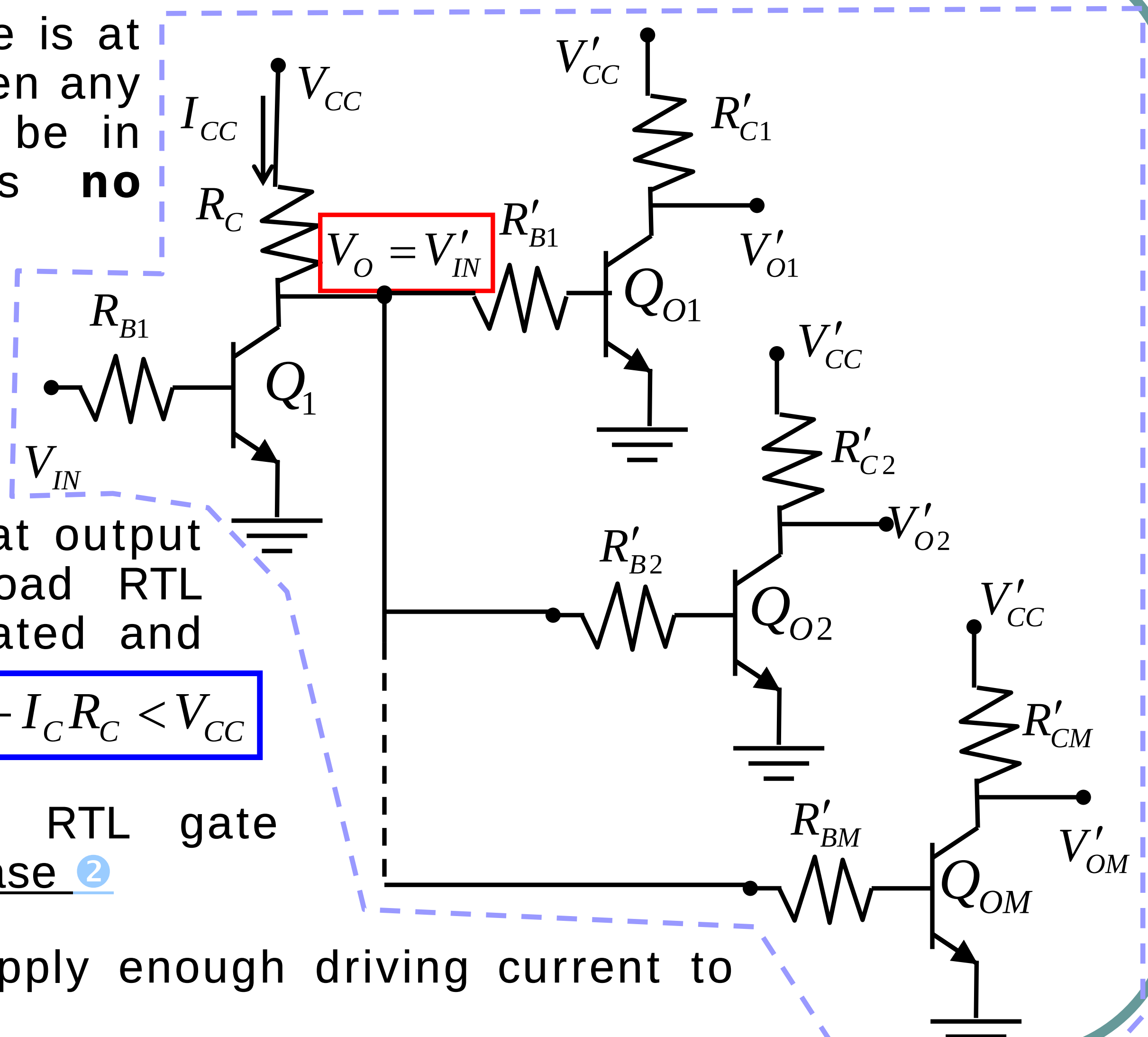
❶When an RTL gate is at output **low** state,then any load RTL gate will be in cut-off and draws **no** current

$$\boxed{\begin{aligned} V_{OL} &= V_{CE}(sat) \\ &= V'_{IN} < V_{BE}(FA) \end{aligned}}$$



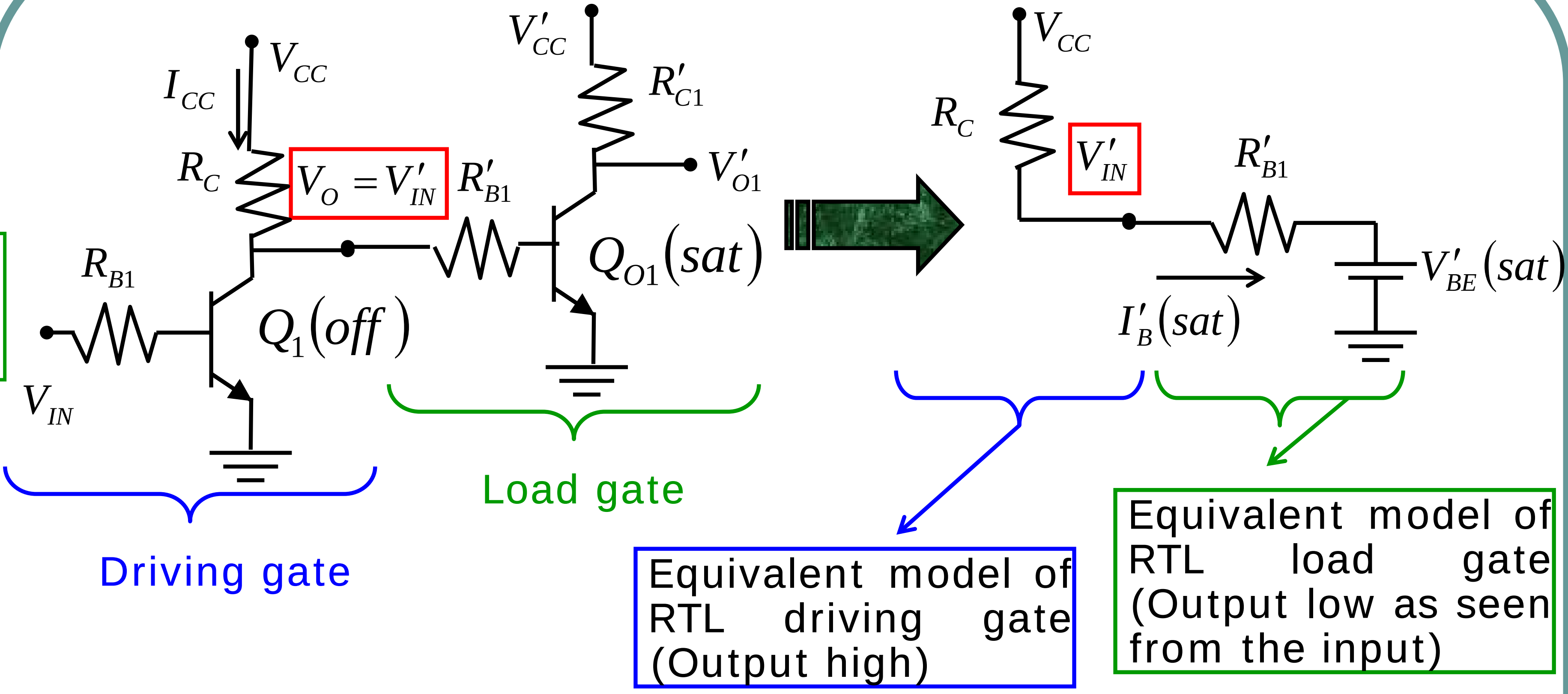
❷When an RTL gate is at output **high** state,then all load RTL gates will be in saturated and draw current

$$\boxed{V_{OH} = V_{CC} - I_C R_C < V_{CC}}$$

❸Maximum fan-out of RTL gate therefore depends on case ❷

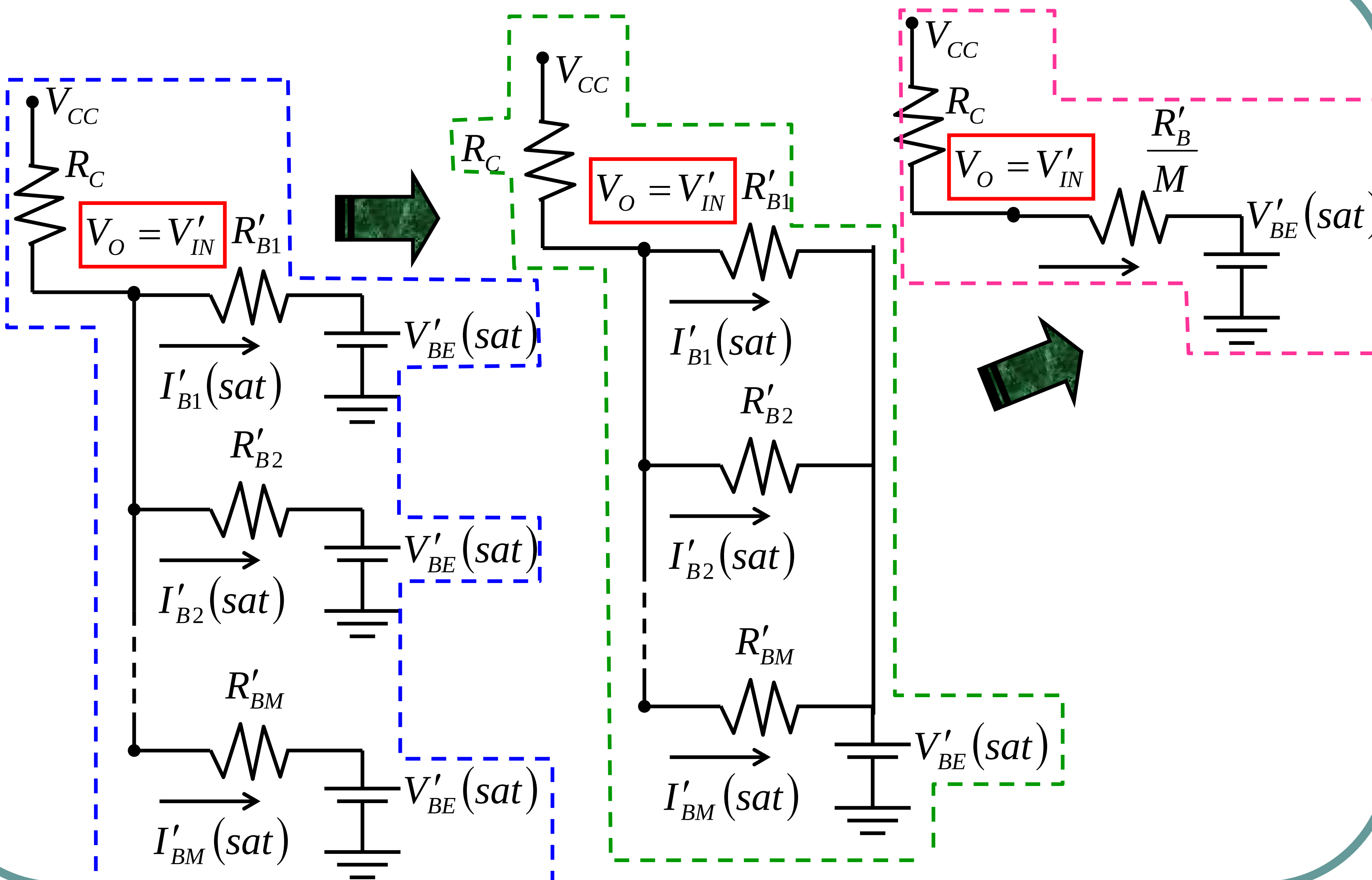
❹ Driving gate must supply enough driving current to saturate all load gates

RTL Fan-Out



V_{CC}
I_{CC}
R_C
$V_O = V'_{IN}$
R_{B1}
V_{IN}
$Q_1(off)$
Driving gate
V'_{CC}
R'_{C1}
V'_{O1}
R'_{B1}
$Q_{O1}(sat)$
Load gate
V_{CC}
R_C
V'_{IN}
R'_{B1}
$V'_{BE}(sat)$
$I'_B(sat)$
Equivalent model of RTL driving gate (Output high)
Equivalent model of RTL load gate (Output low as seen from the input)

RTL Fan-Out



V_{CC}
R_C
$V_O = V'_{IN}$
R'_{B1}
$I'_{B1}(sat)$
R'_{B2}
$I'_{B2}(sat)$
R'_{BM}
$I'_{BM}(sat)$
$V'_{BE}(sat)$
$\frac{R'_B}{M}$

RTL Fan-Out

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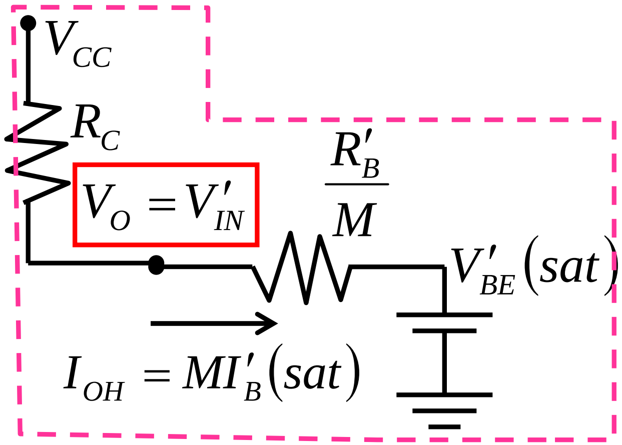
$$\frac{V_{CC}-V_O}{R_C}=\frac{V_O-V_{BE}(sat)}{R_B'/M}$$

$$M=\frac{(V_{CC}-V_O)/R_C}{(V_O-V_{BE}(sat))/R_B'} \quad \bigstar$$

$$M=\frac{I_{OH}}{I_{IH}}$$



❶ As M increases, the collector current of the driving gate increases, i.e. V_{OH} decreases. V_{OH} should be large enough to saturate all load gates

$$V_{OH}(\min)=V_{IH}=\frac{V_{CC}-V_{CE}(sat)}{\beta_F R_C'}R_B'+V_{BE}'(sat) \quad \bigstar\bigstar$$ (Proved in p. 10 of CH.4)

❷ Now, substitutiong V_{OH}(min) (★★) as V_o in (★) gives the maximum fan-out

RTL Fan-Out

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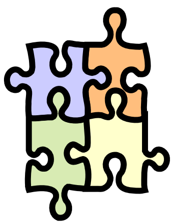
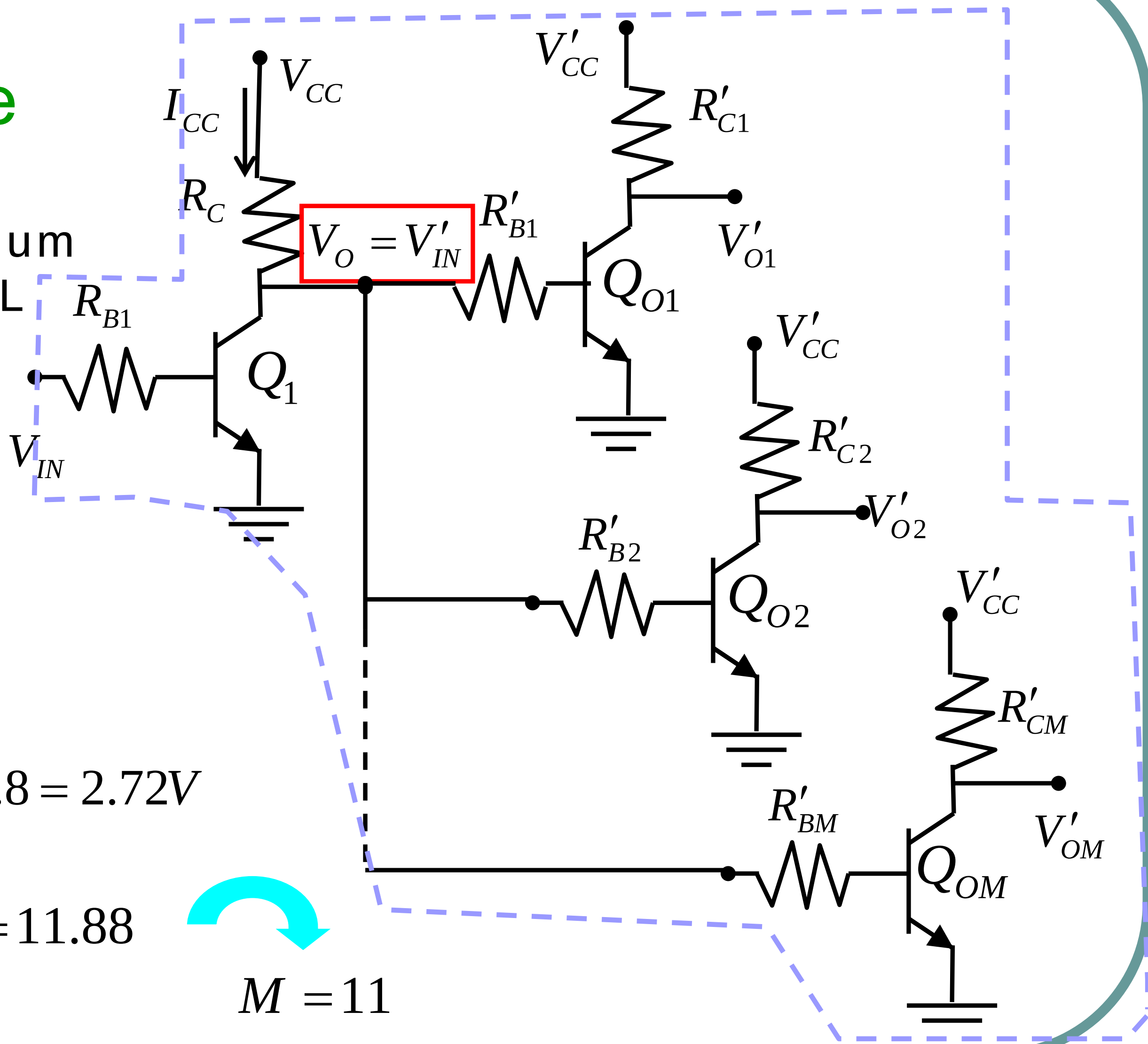


- Example

Determine the maximum fan-out for driving RTL gate, assuming $V_{CE}(sat) = 0.2V$, $V_{BE}(sat) = 0.8V$, $\beta_F = 25, V_{CC} = 5V$, $R_C = 1k\Omega$, $R_B = 10k\Omega$



- Solution

$$V_{OH}(\min) = \frac{5-0.2}{25} \times 10 + 0.8 = 2.72V$$

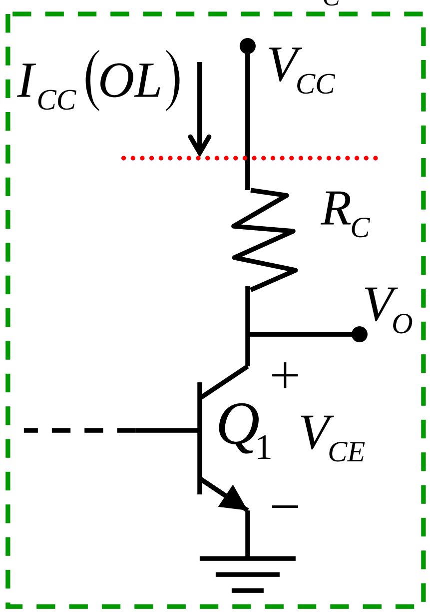
But
$$M = \frac{(5-2.72)/1}{(2.72-0.8)/10} = 11.88$$

$$M = 11$$

RTL Power-Dissipation

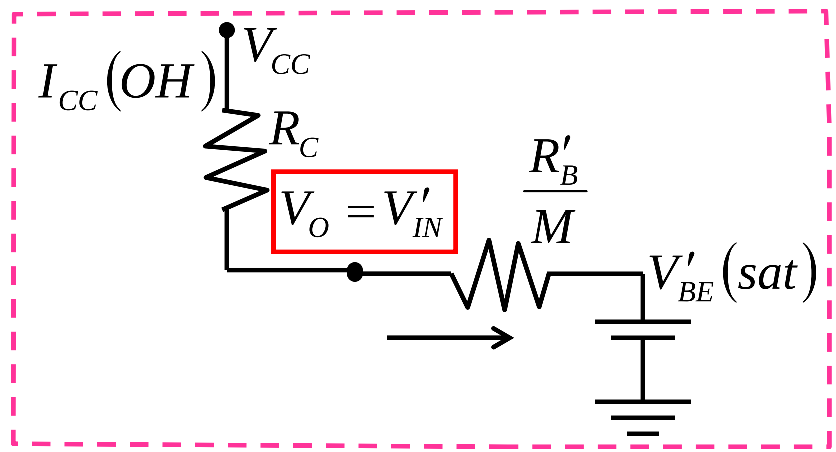
Output low supplied current = $I_{CC}(OL)$

$$I_{CC}(OL) = \frac{V_{CC} - V_{CE}(sat)}{R_C}$$



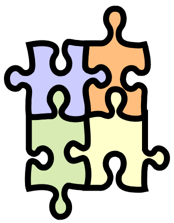
Output high supplied current assuming M-load gates = $I_{CC}(OH)$

$$I_{CC}(OH) = \frac{V_{CC} - V_{BE}(sat)}{R_C + \dfrac{R'_B}{M}}$$



$$P_{CC}(avg) = V_{CC}\left(\frac{I_{CC}(OH) + I_{CC}(OL)}{2}\right)$$

RTL Power-Dissipation



- Example

Determine the average dissipated power for

A. No load

B. Fan-out of 1

Assuming $V_{CE}(sat)=0.2V$, $V_{BE}(sat)=0.8V$, $\beta_F=25$, $V_{CC}=5V$, $R_C=1k\Omega$, $R_B=10k\Omega$

- Solution

A. No load:

$$I_{CC}(OL)=\frac{V_{CC}-V_{CE}(sat)}{R_C}=\frac{5-0.2}{1}=4.8mA$$

$$I_{CC}(OH)=0mA$$

$$P_{CC}(avg)=5\left(\frac{4.8}{2}\right)=12mW$$

B. $M=1$:

$$I_{CC}(OL)=\frac{V_{CC}-V_{CE}(sat)}{R_C}=\frac{5-0.2}{1}=4.8mA$$

$$I_{CC}(OH)=\frac{V_{CC}-V_{BE}(sat)}{R_C+\frac{R_B'}{M}}=\frac{5-0.8}{1+10}=0.382mA$$

$$P_{CC}(avg)=5\left(\frac{4.8+0.382}{2}\right)=12.96mW$$

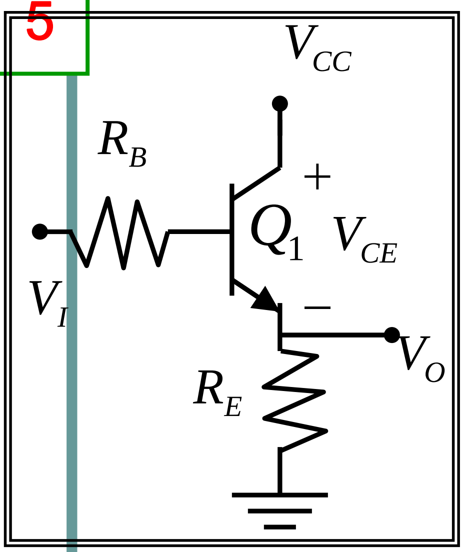
Basic RTL Non-Inverter *(Emitter Follower in Analog Cct's)*

- Voltage-Transfer Characteristics

For $V_I - GND < V_{BE}(FA)$ ⇒ $I_B = 0, I_C = 0, V_O = 0 = V_{OL}$

For $V_I - GND \geq V_{BE}(FA)$ ⇒ $I_B = (V_I - V_{BE}(FA))/(R_B + (1+\beta_F)R_E)$, $V_O = R_E(V_I - V_{BE}(FA)/(R_B/(1+\beta_F) + R_E)$

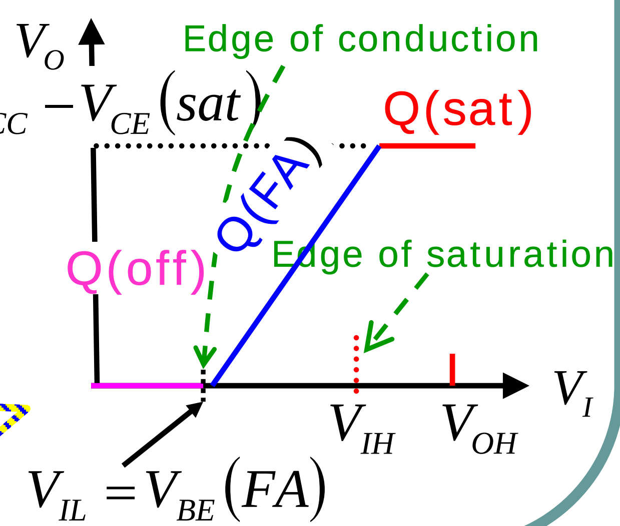
For $V_I - GND \geq V_{IH}$ ⇒ $I_E = (V_{CC} - V_{CE}(sat))/R_E$, $V_O = V_{CC} - V_{CE}(sat) = V_{OH}$



$$V_{IH} = I_B(sat)R_B + V_{BE}(sat) + I_E(sat)R_E$$

$$= I_E(EOS)\left(R_E + \frac{R_B}{(1+\beta_F)}\right) + V_{BE}(sat)$$

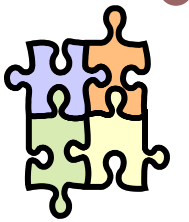
$$V_{OH} = V_{CC} - V_{CE}(sat)$$



$$V_{IH} = \frac{V_{CC} - V_{CE}(sat)}{R_E}\left(R_E + \frac{R_B}{(1+\beta_F)}\right) + V_{BE}(sat)$$

BJT Non-Inverter (Basic RTL Non-Inverter)

- Example

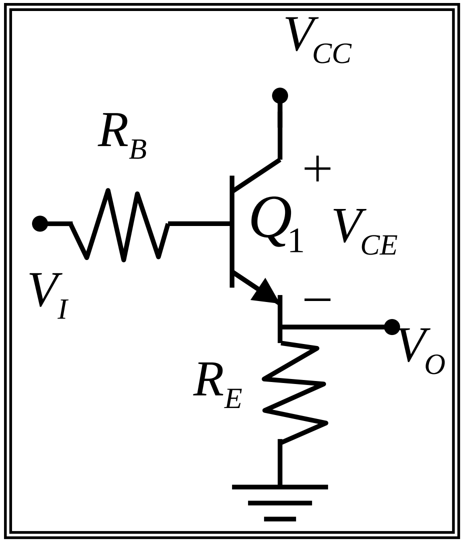


Assume V_{CC} = 5 V, R_E = 1kΩ , R_B = 10 kΩ, β_F=25;
$V_{CE}(sat)$=0.2V, $V_{BE}(sat)$=0.8V, $V_{BE}(FA)$=0.7V,

Determine the <u>VTC</u> parameters

- Solution

V_{IL} = 0.7 V, V_{IH} = 7.45 V,
V_{OL} = 0.0 V, V_{OH} = 4.8 V,



Basic RTL OR Gate

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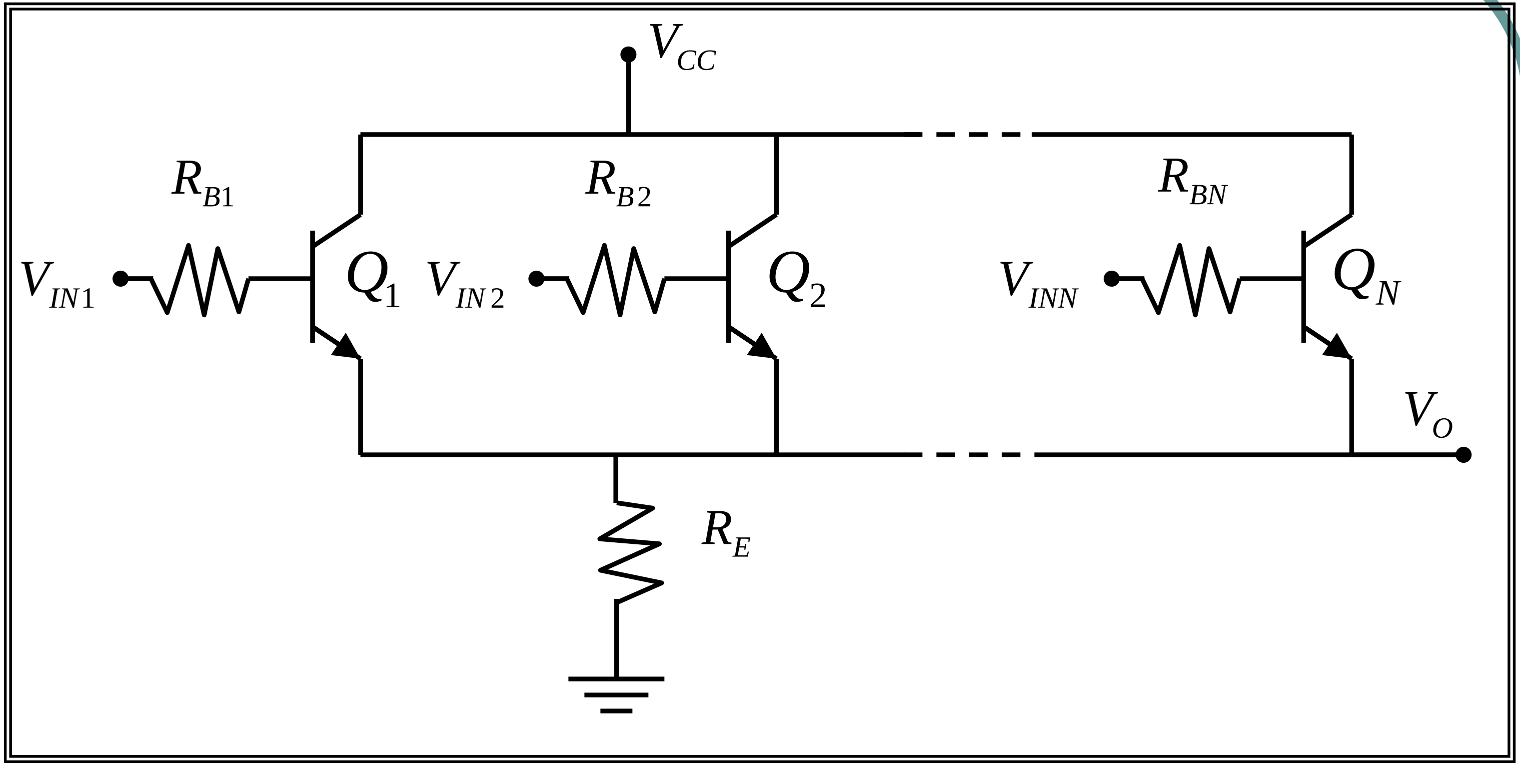

If all inputs are less than V_{BE}(FA) $\Rightarrow$ $V_O = 0$ Low

If at <u>least one input</u> is greater than V_{IH} $\Rightarrow$ $V_O = V_{CC} - V_{CE}(sat)$ High